ENVIRONMENTAL CONTAMINANTS IN BALD EAGLES IN THE COLUMBIA RIVER ESTUARY

ROBERT G. ANTHONY, U.S. Fish and Wildlife Service, Oregon Cooperative Wildlife Research Unit, Oregon State University, Corvallis, OR 97331-3803
MONTE G. GARRETT,[1] Oregon Cooperative Wildlife Research Unit, Oregon State University, Corvallis, OR 97331-3803
CAROL A. SCHULER, U.S. Fish and Wildlife Service, Portland Field Office, 2600 S.E. 98th Avenue, Portland, OR 97266

Abstract: Eggs, blood, and carcasses of bald eagles (*Haliaeetus leucocephalus*) and fish were collected and breeding success of eagles was monitored in the Columbia River estuary, 1980–87, to determine if contaminants were having an effect on productivity. High levels of dichloro diphenyl dichloroethylene (DDE), polychlorinated biphenyls (PCB's), and 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) were found in eggs, blood from adults, and 2 eagle carcasses. Detectable levels of DDE and PCB's were found in blood of nestlings indicating they were exposed to these contaminants early in life. Increasing concentrations of DDE and PCB's with age also indicated accumulation of these contaminants. Adult eagles also had higher levels of mercury (Hg) in blood than subadults or young indicating accumulation with age. The high levels of DDE and PCB's were associated with eggshell thinning ($\bar{x}$ = 10%) and with productivity ($\bar{x}$ = 0.56 young/occupied site) that was lower than that of healthy populations (i.e., ≥1.00 young/occupied site). DDE and PCB's had a deleterious effect on reproduction of bald eagles in the estuary. The role dioxins play in eagle reproduction remains unclear, but concentrations in eagle eggs were similar to those in laboratory studies on other species where dioxins adversely affected hatchability of eggs. Probable sources of these contaminants include dredged river sediments and hydroelectric dams, and the proper management of each may reduce the amount of contaminants released into the Columbia River estuary.

J. WILDL. MANAGE. 57(1):10–19

Declines in many populations of bald eagles from 1950 to 1975 (Broley 1958, Sprunt and Ligas 1966, Abbott 1967) led to the species being classified as endangered in 43 of the 48 contiguous states, and threatened in Oregon, Washington, Minnesota, Wisconsin, and Michigan (U.S. Fish and Wildl. Serv. 1979). Many of the declines were associated with environmental contaminants, either by circumstantial evidence or by examining eggs for contaminants (Stickel et al. 1966; Krantz et al. 1970; Wiemeyer et al. 1972, 1984); however, the exact physiological mechanism of how contaminants affect eggshell formation has been difficult to isolate (Grier 1974). Since the banning of DDT (dichloro diphenyl trichloroethane), bald eagle populations have increased throughout most of the contiguous United States.

Substantial populations of bald eagles occur in Oregon (Isaacs et al. 1983) and Washington (McAllister et al. 1986), and levels of productivity have been close to that required for delisting the species (U.S. Fish and Wildl. Serv. 1986). However, surveys in both states have indicated that reproductive success of bald eagles has been poor and variable on the Columbia River estuary. In contrast to other bald eagle populations, the productivity of eagles in this area has not increased, and a possible cause of these low reproductive rates was environmental contaminants. Therefore, we documented nesting success and determined levels of organochlorine pesticides, polychlorinated biphenyls (PCB's), 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), and heavy metals in bald eagles from the Columbia River estuary.

We thank G. L. Dorsey, K. McGarigal, and J. W. Watson for help with field work. J. C. Elliot, G. L. Dorsey, C. J. Henny, J. S. Moore, S. N. Wiemeyer, and 2 anonymous reviewers provided valuable comments on an earlier draft. This research was supported by the U.S. Army Corps of Engineers through a contract to the Oregon Cooperative Wildlife Research Unit; Oregon State University, Oregon Department of Fish and Wildlife, the U.S. Fish and Wildlife Service, and Wildlife Management Institute cooperating. Additionally, we thank the U.S. Environmental Protection Agency (EPA) and the Lower Columbia River Bi-State Water Quality Program for their support of dioxin analyses of eagle eggs. This is Technical Paper No. 9139 of the Oregon Agricultural Experiment Station, Oregon State University, Corvallis.

[1] Present address: Pacific Power and Light Company, 920 S.W. Sixth Avenue, Portland, OR 97204.

METHODS

Field Procedures and Sample Collection

Environmental contaminants in bald eagles from the Columbia River estuary were assessed from collections of 19 intact eggs, 12 eggshell fragments, 22 blood samples, and 2 carcasses. Breeding success of bald eagles on 22 occupied breeding territories was investigated over 7 years (1980–87). Ages of bald eagles were estimated by examination of plumage (Southern 1964, Servheen 1975) and classified as nestlings (prior to fledging), subadults (hatching year to maturity), or adults (maturity). We assessed nesting activity and productivity of bald eagles by aerial and ground surveys as described by Isaacs et al. (1983). Terminology used to describe nesting success follows Postupalsky (1974). We surveyed nesting territories from fixed-wing aircraft and the ground (or by boat) at least twice each year: once during the early incubation period (mid- to late Mar) to determine occupancy of nest sites, and later in the same year (late May to early Jun) to determine nesting success and number of young produced.

When nesting attempts were classified as unsuccessful, we climbed nest trees to assess possible causes of nesting failure. Nest trees that contained nestlings were climbed when the young were 8–11 weeks old to obtain blood samples for contaminant analyses. Nests and the general area surrounding nest trees were searched for prey remains, eggshell fragments, and addled eggs. In 1986 and 1987, 16 fresh eggs were collected from 9 nesting territories for contaminant analysis. One addled egg was collected in 1985 and 2 in 1991. Eggshell fragments were collected from 12 additional nests that failed to produce young.

Large-scale suckers (*Catostomus macrocheilus*), American shad (*Alsoa sapidissima*), peamouth (*Mylocheilus caurinus*), and northern squawfish (*Ptychocheilus oregonensis*) also were collected and chemically analyzed to determine if potential eagle prey items were accumulating environmental contaminants. Each fish sample was a homogenized composite of 3–5 individuals of the same species that were collected from the same local area of the estuary.

Contaminant Analyses

Levels of environmental contaminants in bald eagles were determined by residue analysis of samples of whole blood, contents of eggs, and carcasses found in the study area. We shipped fresh carcasses on dry ice to the National Wildlife Health Research Center in Madison, Wisconsin for necropsy. Liver, brain, and whole carcasses were forwarded by the Center to Patuxent Wildlife Research Center (PWRC), Laurel, Maryland for contaminant analysis. Intact eggs were wrapped in clean foil and refrigerated. The eggs were excised on the equator, and the contents stored in chemically cleansed glass jars (washed with hexane and rinsed with deionized water and residue-grade acetone). We collected blood samples using heparinized glass syringes that were washed and rinsed 3 times with residue-grade acetone. The 6- to 12-cc samples were stored in glass vials that had been washed with nitric acid and rinsed with residue-grade acetone and covered with teflon-lined lids. We froze and stored blood and egg samples for ≥3 months prior to residue analysis. Therefore, the DDE levels in blood reported are minimum values because there is a loss of DDE within 2 weeks after freezing (Wiemeyer et al. 1984).

Organochlorine pesticides and PCB analyses on eagle blood and carcasses were conducted by the PWRC Chemistry Section. Eggs and fish tissues were analyzed by the Weyerhaeuser Analytical and Testing Service, Tacoma, Washington. Sample preparation, extraction, and cleanup were conducted as described by Cromartie et al. (1975) and Kaiser et al. (1980) with the following modifications. Special precautions were taken in rinsing glassware to achieve lower detection limits for the blood samples. For blood samples only, the residues were corrected for the background as measured by procedural blanks. Quantification was by electron capture gas-liquid chromatography. PWRC utilized a 1.83- × 4-mm glass column packed with 1.5% SP-2250/1.95% SP-2401 on 100/120 mesh Supelcoport. Weyerhaeuser used dual 30-cm capillary columns (DB-1 and DB-1701).

Analysis for metals in eggs was performed by the PWRC Chemistry Section. The analysis of blood and fish tissues was performed by the University of Missouri Environmental Trace Substances Research Center. Mercury samples were digested in a manner similar to that described by Monk (1961) except that for the blood samples, nitric acid alone was used in the tissue digestion. Analysis was by cold vapor atomic absorption spectroscopy as described by Hatch and Ott (1968). Egg samples were analyzed for lead (Pb) and cadmium (Cd) as described by

Table 1. Eggshell thickness and concentrations (ppm wet mass basis) of environmental contaminants in fresh bald eagle eggs, Columbia River estuary, 1985–87.

Eggshell measurement/ contaminant	*n*	$\bar{x}$	Range
Thickness (mm)	17	0.548	0.495–0.614
% change[a]	17	−10	−19–+5
pp′ DDE	17	9.7	4.0–20.0
pp′ DDD	17	1.4	0.3–2.6
Hexachlorobenzene	17	0.3	ND[b]–0.5
Mirex	17	0.2	ND[b]–0.3
PCB's	17	12.7	4.8–26.7
2,3,7,8-TCDD[c]	5	31.98	5.1–61.0
Mercury	13	0.20	0.13–0.36
Cadmium	13	0.10	0.09–0.11
Lead	13	0.21	0.18–0.28

[a] Compared to mean eggshell thickness (0.6088 mm) of bald eagle eggs before 1946.
[b] ND = None detected at minimum level of detection (organochlorines—0.01).
[c] 2,3,7,8-tetrachlorodibenzo-p-dioxin; analysis includes 2 eggs collected in 1991 and 3 eggs collected in 1987; results given in parts per trillion, wet mass basis.

Table 2. Concentrations of environmental contaminants (ppm wet mass) in blood from bald eagles, Columbia River estuary, 1984–86.[a]

Contaminant	Nestlings (n = 15)	Subadults (n = 4)	Adults (n = 3)
pp′ DDE	0.05	0.31	2.13
	0.01–0.24	0.15–0.70	1.00–3.20
PCB's	0.04	0.53	2.40
	ND[b]–0.13	0.14–1.50	1.40–3.50
Lead	0.23	0.17	0.43
	0.03–0.70	ND[b]–0.27	0.05–1.00
Mercury	0.47	1.50	3.07
	0.19–1.40	ND–3.10	1.30–4.10

[a] Values are mean and ranges.
[b] ND = None detected at minimum level of detection (organochlorines and PCB's—0.01; heavy metals—0.02).

Haseltine et al. (1981) using flame atomic absorption spectroscopy. Blood samples were analyzed as described by Hinderberger et al. (1981) using graphite furnace atomic absorption spectroscopy.

Five eggs were analyzed for 2,3,7,8-TCDD by Alta Analytical Laboratory, Inc., Eldorado Hills, California and by the EPA Environmental Research Laboratory, Duluth, Minnesota. Sample preparation, extraction, and cleanup were conducted as described by Kuel et al. (1989) and Smith et al. (1984). Acceptable performance (recovery variation averaged <26%) on spikes, blanks, and duplicates was documented in laboratory quality control reports.

Egg volume and thickness measurements followed Krantz et al. (1970) and Stickel (1973); residue concentrations in eggs were calculated as g/ml on the basis of total egg volume and converted to ppm assuming a specific gravity of 1.0 (Stickel et al. 1966). We measured eggshell thickness (shell and membranes) at 4 different locations at approximately the equator of each egg. A mean was computed from these measurements, and eggshell thinning was calculated as the percent difference between mean thickness of each egg and mean eggshell thickness (0.6088 mm) of bald eagle eggs from the region prior to 1946 (Anderson and Hickey 1972). All concentrations in this paper are presented on a wet-mass (= wet-weight) basis unless otherwise noted.

Data Analyses

Breeding success was calculated as the percentage of breeding attempts (occupied sites) that were successful in fledging young. Arithmetic means were computed for eggshell thickness, breeding success, and concentrations of organochlorines and heavy metals in tissue samples. We report means and ranges of contaminants in eagle eggs, blood, and prey, because these values provide the best comparison to Wiemeyer et al. (1984). Simple correlation analysis was used to relate breeding success to amount of eggshell thinning and the concentrations of DDE to PCB's in eggs. All statistical tests were performed at the 0.05 level of significance.

RESULTS

Contaminants in Eggs

Analysis of contents of 19 eggs revealed the presence of DDE; dichloro diphenyl dichloroethane (DDD); hexachlorobenzene; mirex; PCB's; 2,3,7,8-TCDD; Hg; Cd; and Pb (Table 1). Of the organochlorines, DDD; hexachlorobenzene; and mirex concentrations were considered to be low (<1.00 ppm), but concentrations of DDE; PCB's; and 2,3,7,8-TCDD in egg contents were elevated (Table 1). Concentrations of DDE ranged from 4.0 to 20.0 ppm ($\bar{x}$ = 9.7 ppm); concentrations of PCB's ranged from 4.8 to 26.7 ppm ($\bar{x}$ = 12.7 ppm); and concentrations of 2,3,7,8-TCDD ranged from 5.1 to 61 ppt ($\bar{x}$ = 31.9). Concentrations of 2,3,7,8-TCDD in 1991 eggs were higher (60, 61 ppt) than eggs collected in 1986–87 (5.1–24.7 ppt). Eggshell thickness was variable and ranged from normal (similar to pre-DDT average of 0.6088 mm) to 44% thinner than the pre-DDT average;

Table 3. Concentrations of organochlorines, PCB's, and heavy metals (ppm wet mass) in whole body samples of fish prey species, Columbia River estuary, 1986.[a]

Contaminant	Large scale sucker[b]	Peamouth[b]	American shad[b]	Northern squawfish[b]
pp' DDE	0.07	0.41		0.20
	ND[c]–0.12	0.34–0.52	ND = 0.14	ND–0.37
pp' DDD	0.08	0.15		0.21
	0.05–0.14	0.08–0.21	0.08–0.11	0.10–0.40
pp' DDT	0.02	[d]		
	ND–0.03	ND–ND	0.05–0.05	ND–0.08
Total PCB's	0.85	2.1		1.7
	0.74–0.29	0.68–3.30	0.26–0.49	1.00–2.30
Cadmium	0.052	0.061		
	0.034–0.084	0.043–0.084	0.054[e]	0.17[e]
Lead	0.10			
	ND–0.17	ND–0.16	ND[e]	ND[e]
Mercury	0.094	0.12		
	0.042–0.17	0.061–0.16	0.039[e]	0.19[e]

[a] Values are arithmetic means and ranges.
[b] Each fish sample was a homogenized composite of 3–5 individuals of the same species that were collected from the same local area; n = 4, 3, 2, and 3 for sucker, peamouth, shad, and squawfish, respectively, unless otherwise noted.
[c] ND = none detected at minimum level of detection (organochlorines and PCB's—0.01; lead—0.08).
[d] Means were not calculated if <50% of the samples contained detectable concentrations or <3 samples were analyzed.
[e] n = 1.

mean eggshell thickness was 10% thinner than the pre-DDT average. Concentrations of Hg, Cd, and Pb, were <1.00 ppm (Table 1).

Contaminants in Blood

Analysis of 22 blood samples revealed detectable levels of DDE, PCB's, Pb, and Hg in several samples (Table 2). Dieldrin, trans-nonachlor, cis-nonachlor, and endrin were detected in a few samples but were low (1.00 ppm) in concentration. Concentrations of Pb were low (<1.00 ppm), but concentrations of DDE, PCB's, and Hg were higher in adults and subadults than nestlings indicating increased accumulation with age. Detectable concentrations of DDE were found in all nestlings (8–11 weeks of age), and about half of the nestlings had detectable concentrations of PCB's.

Contaminants in Eagle Carcasses

Carcasses of 2 bald eagles (1 5-week-old nestling, and 1 adult male) had detectable levels of environmental contaminants. Cause of death of the nestling could not be determined, but elevated concentrations of DDE (7.0 ppm) and PCB's (11.0 ppm) were detected in the whole carcass of the nestling. The adult male was found on the shoreline of the Columbia River, Pacific County, Washington, and the proximate cause of death was diagnosed as drowning. However, analysis of whole carcass samples revealed elevated concentrations of DDE (31.0 ppm) and PCB's (49.0 ppm) with lower concentrations in the brain (2.8 and 5.5 ppm, respectively), which could have been responsible, in part, for its poor health and death.

Contaminants in Prey

Analysis of 12 composite fish samples collected from the Columbia River showed detectable concentrations of DDE (range = <0.01–0.52 ppm), DDD (range = 0.05–0.40 ppm), and PCB's (range = 0.26–3.3 ppm) (Table 3). DDT, chlordane, dieldrin, endrin, heptachlor epoxide, hexachlorobenzene, nonachlor, and oxychlordane also were detected but at low concentrations or in only a few samples (Table 3). DDD and PCB's were detected in all of the fish samples analyzed and detectable concentrations of DDE occurred in 9 of the 12 samples. Concentrations of Cd and Hg were slightly elevated (>1.00 pm) in some samples.

Relationship of Contaminants to Productivity

Productivity of bald eagles on the lower Columbia River was lower than statewide averages during this study. From 1980 to 1987, only 39% of the occupied breeding territories were successful in fledging young, and productivity averaged 0.56 young/occupied site (Table 4). The low breeding success was more pronounced for eagles on the Washington side of the river (29% success, 0.40 young/occupied site) as compared with the Oregon side (48% success, 0.70 young/occupied site).

Table 4. Success and productivity of bald eagle nest sites, Columbia River estuary, Oregon and Washington, 1980–87.

	1980	1981	1982	1983	1984	1985	1986[a]	1987[a]	Total
Oregon:									
No. occupied sites	5	7	7	7	7	10	9	8	60
% success	0	43	43	57	71	60	67	25	48
No. young produced	0	4	4	6	8	8	9	3	42
Young/occupied site	0.00	0.57	0.57	0.86	1.14	0.80	1.00	0.38	0.70
Washington:									
No. occupied sites	2	3	2	5	10	11	7	12	52
% success	0	33	50	20	20	9	86	27	29
No. young produced	0	1	2	1	3	2	8	4	21
Young/occupied site	0.00	0.33	1.00	0.20	0.30	0.18	1.14	0.36	0.40
Combined									
No. occupied sites	7	10	9	12	17	21	16	20	112
% success	0	40	44	42	41	33	75	25	39
No. young produced	0	5	6	7	11	10	17	7	63
Young/occupied site	0.00	0.50	0.67	0.58	0.65	0.48	1.06	0.35	0.56

[a] Fresh eggs were collected from 6 and 3 sites in 1986 and 1987, respectively; these sites were not included in any of the above values.

Breeding success and the amount of eggshell thinning were negatively correlated ($r = -0.52$, $n = 14$, $P < 0.05$) (Fig. 1). Most eggs and eggshell fragments showed considerable amounts of thinning except for the samples from 1 site. The mean (−10%) and maximum (−44% for 1 sample of eggshell fragments) eggshell thinning indicate considerable reduction in shell thickness for the population.

DISCUSSION

High concentrations of DDE and PCB's in eggs and carcasses were associated with marked eggshell thinning and low reproductive success in bald eagles from the Columbia River estuary. Concentrations of DDE and PCB's were lower in eagle blood but indicated an accumulation with age. The detectable levels (0.01–0.13 ppm) of DDE and PCB's in blood of 8- to 10-week-old nestlings indicated an exposure to these contaminants at an early age. Because Charnetski (1976) found a dilution of DDT residues with growth in tissues of ducklings hatched from contaminated females, we believe the DDE and PCB's found in nestling eagles were probably acquired from prey from the river and not acquired from lipids deposited in the eggs. Steidl et al. (1991) recently reported eggshell thinning and reduced reproductive success in osprey (*Pandion haliaetus*) on the Delaware Bay estuary that were associated with elevated levels of DDE and PCB's in osprey eggs and fish from the Bay. Fish from the Columbia River, including largescale sucker, American shad, common carp, and peamouth comprised over 60% of nestlings' diets on the estuary (Watson et al. 1991). Chemical analysis of 3 of these species showed slightly elevated concentrations of DDE, DDD, and PCB's; however, DDE concentrations in all fish samples were below dietary levels found to cause significant eggshell thinning in American kestrels (*Falco sparverius*) (Wiemeyer and Porter 1970, Lincer 1975). In contrast, all the fish samples had PCB residues greater than the national geometric mean for the U.S. Fish and Wildlife Service's National Pesticide Monitoring Program (NPMP) (Schmitt et al. 1985). Residues in 10 of the 12 samples exceeded the PCB recommendation of 0.5 ppm for protection of fish-eating birds and mammals (Natl. Academy of Sci. 1973), although only 1 sample had a PCB concentration that was greater than dietary concentrations shown to reduce hatchability in chickens (*Gallus gallus*) (Cecil et al. 1974) and screech owl (*Otus asio*) eggs (McLane and Hughes 1980). Other investigations indicate that fish-eating birds preyed upon by bald eagles are a greater source of organochlorine compounds in eagle diets than fish (Frenzel 1984, Kozie and Anderson 1991). This is probably occurring in the Columbia River, because fish samples do not show excessively high concentrations of DDE, and bald eagles do feed on fish-eating birds there (Watson et al. 1991).

Declines in raptor populations caused by organochlorine pesticides (Henny 1972) have been associated with eggshell thinning induced by the DDT-metabolite, DDE (Newton 1979:239). DDE has been shown to cause thinning of eggshells experimentally in raptors and other birds (Bitman et al. 1969, Porter and Wiemeyer 1969,

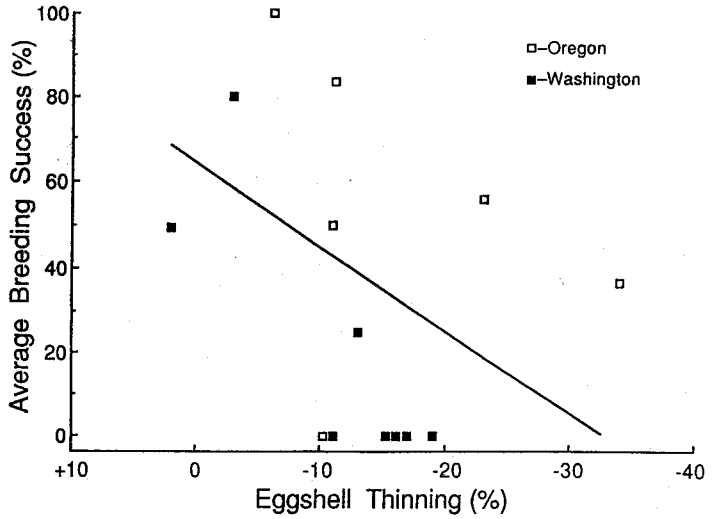

Fig. 1. Inverse relationship ($r = -0.52$, $n = 14$, $P < 0.05$) between breeding success and eggshell thinning in bald eagles, Columbia River estuary, 1980–87.

Wiemeyer and Porter 1970, Longcore and Samson 1973, Lincer 1975) and has been linked to significant eggshell thinning in wild populations of bald eagles (Hickey and Anderson 1968, Krantz et al. 1970, Anderson and Hickey 1972, Wiemeyer et al. 1972, Grier 1974). Wiemeyer et al. (1984) found significant correlations between DDE residues in eggs, eggshell thinning, and decreased reproductive success in regional bald eagle populations. DDT use in North America dropped to nearly zero in 1973 following its ban in the United States in 1972 (Newton 1979:251), and most bald eagle populations stopped declining (Hamerstrom et al. 1975) and have increased since that time (Grier 1982).

Our data on concentrations of the above contaminants in eggs are unique for the Pacific Northwest in that eggs were collected fresh during incubation. Most analyses of egg contents from bald eagles have been performed on unhatched (addled) eggs that were collected later in the breeding season (Wiemeyer et al. 1984); therefore, one might expect higher concentrations of DDE and PCB's from unhatched eggs than a more random sample of fresh eggs. Concentrations of DDE and PCB's in fresh eggs in our study were the highest recorded for bald eagle populations in the western United States, and they are surpassed only by levels found in eggs from the Great Lake States, Chesapeake Bay, and Maine during the 1970's (Wiemeyer et al. 1984). Concentrations of Hg in blood and concentrations of Hg, Cd, and Cu in fish tissues were elevated, but their potential influence on eagles is not clear. Three of the 12 fish samples had Hg concentrations that exceeded dietary levels shown to interfere with successful reproduction in nesting mallards (Heinz 1979).

Wiemeyer et al. (1984) predicted rates of reproduction (5-yr average) of bald eagle populations with various levels of DDE contamination. This relationship was significant ($P < 0.05$) and was expressed by the equation $Y = 1.081 - 0.709 \log_{10}X$, where Y is mean reproductive rate and X is mean DDE in eggs. Grubb et al. (1990) found that their equation accurately predicted productivity of bald eagles from DDE levels in eggs from Arizona. If we apply this equation to our data from the Columbia River estuary (i.e., $\bar{x}$ DDE concentration in eggs = 9.7), the predicted level of productivity would be 0.38 young/occupied site. This value is similar to that from this study of 0.40 for the Washington side where 13 of the 16 fresh eggs were collected. These levels of reproduction were considerably lower than the statewide average of 62% success and 0.93 young/occupied site for Oregon from 1978 to 1987 (F. B. Isaacs and R. G. Anthony, unpubl. data) and the goals of 65% and 1.00 young/occupied site for delisting the Pacific States' bald eagle population (U.S. Fish and Wildl. Serv. 1986). Based on these findings, we conclude that DDE has had a negative impact on reproduction of bald eagles in the Columbia River estuary.

The effects of PCB's on reproduction of bald eagles are more difficult to ascertain because PCB residues in eggs are commonly correlated

with DDE residues (Haseltine et al. 1981, Wiemeyer et al. 1984). This was the case in our study, as PCB residues were highly correlated ($r = 0.91$, $n = 14$, $P < 0.05$) with DDE residues. Therefore, the separation of the effects of PCB's from those of DDE was difficult, and there is some uncertainty as to the effect of PCB's on bald eagles (Wiemeyer et al. 1984). However, PCB's have caused adverse effects on reproduction of mallards (*Anas platyrhynchos*; Haseltine and Prouty 1980), screech owls (McLane and Hughes 1980), and Atlantic puffins (*Fraterula arctica*; Harris and Osborn 1981) in experimental studies. More recently, Kubiak et al. (1989) conducted an analysis of data on Forster's tern (*Sterna forsteri*) populations from Lake Michigan and concluded that certain PCB congeners were responsible for the embryotoxicity at 1 colony.

In addition to DDE and PCB's, preliminary evidence indicates that bald eagles are also accumulating dioxins, namely 2,3,7,8-TCDD, which has been reported to be the most toxic synthetic compound ever tested in laboratory conditions (Eisler 1986). Concentrations in the 2 eggs collected in 1991 were substantially higher than eggs collected in 1987, which may have been due to the location of the egg collections in 1987 (tributaries of the Estuary), lost residues in the 1987 eggs due to lengthy storage time, or normal sample variability. Residues of 2,3,7,8-TCDD in the 1991 eagle eggs (60, 61 ppt) from the Columbia River were greater than the median concentration (37.3 ppt) found in Forster's tern eggs from Lake Michigan that was associated with impaired reproductive success (Kubiak et al. 1989). As with DDE and PCB's, the probable source of dioxins would be through consumption of contaminated prey from the river. Preliminary analysis of fish collected from the river in 1990 and 1991 showed a mean 2,3,7,8-TCDD concentration of 2.8 ppt (range = <1.0–9.0 ppt, $n = 15$) (C. A. Schuler, unpubl. data). Although a predator effect level has not been developed for dioxin, a concentration of greater than 0.07 ppt is being used as a fish consumption guideline for protection of human health (U.S. Environ. Prot. Agency 1986). Mean dioxin concentrations in fish from the Columbia River were 40 times greater than the EPA's guideline. The impacts of dioxins are not clearly understood, but preliminary data indicate that dioxin could be an additional threat to nesting bald eagles along the Columbia River.

Because the use of DDT has been banned from the United States, the source(s) of DDE in this bald eagle population is of concern. Potential sources include avian prey that migrate to Central or South America where DDT is still being used, and/or DDE present in sediments, water, and food chains of the Columbia River estuary. Because breeding pairs were present on their territories the entire year (Watson et al. 1991), eagles were probably being contaminated through their food chain from the estuary. This conclusion is supported by Henny et al. (1981) who found elevated concentrations of DDE and PCB's in mink (*Mustela vison*) and river otter (*Lutra canadensis*) from the Columbia River. Both species are residents there and feed primarily on fish; so their functional role in the ecosystem is similar to that of bald eagles. Henny et al. (1984) also found elevated levels of DDE and PCB's in black-crowned night heron (*Nycticorax nycticorax*) eggs from the Columbia River in southcentral Washington. In addition, we found detectable levels of DDE ($\bar{x} = 0.04$ ppm) in all samples of blood from nestling eagles that were approximately 2 and 4 times those found in the Klamath Basin and Cascade Lakes, respectively (Frenzel 1984). This indicates that nestling bald eagles were being exposed to DDE early in life.

The sources of PCB's in the environment are numerous; they are present in plastics, coolants, and electrical transformers. This group of contaminants is likely entering the Columbia River system from hydroelectric dams and is persistent in the environment from historic exposures. Dioxins are discharged to the Columbia River from both point and nonpoint source pollution. Sources of dioxins include leaded and diesel fuels, bleached wood pulp, wood preservatives, sewage chlorination, petroleum refinement, hazardous waste incinerators, and forest fires.

Our data and the results of other studies (Henny et al. 1981, Henny et al. 1984) indicate the presence of significant amounts of DDE, PCB's and dioxins in the Columbia River estuary. Other studies have documented reduced reproductive success of osprey in Delaware Bay (Steidl et al. 1991) and bald eagles in Chesapeake Bay (Wiemeyer et al. 1984), which were associated with eggshell thinning and elevated levels of DDE and PCB's in eggs. All of these studies substantiate the persistence of DDE and PCB's in the environment. Because contaminants often are found in bottom sediments, dredging activ-

ities present a possible hazard. Seelye et al. (1982) demonstrated the potential for uptake of DDE and PCB's by fish as a result of dredging, and fish were the major prey items of eagles in Columbia River estuary (Watson et al. 1991). Steidl et al. (1991) suggested that the source of DDE and PCB's in ospreys from Delaware Bay was from bottom sediments and dredging activities.

MANAGEMENT AND RESEARCH IMPLICATIONS

The Columbia River estuary serves as a sump for the entire Columbia River Basin, which drains 7 states and a Canadian province (nearly 260,000 square miles). The estuary is exposed to a variety of environmental contaminants through municipal and industrial permitted discharges, urban and industrial nonpoint pollution, accidental spills of oil and hazardous materials, agricultural runoff, and accelerated population growth, all of which threaten the viability of the estuary. Efforts to understand and develop solutions to pollution problems in the Columbia River should focus on the entire river basin. Bald eagles and other wildlife species are not exposed to a single contaminant, but to a mixture of contaminants that are discharged or drain into the river basin.

More information is needed on levels of DDT, PCB's, and dioxins in all parts of the Columbia River estuary, particularly in important eagle foraging areas, to determine the source of these contaminants. The potential resuspension of contaminants by dredging activities in the estuary needs further investigation so dredging can be conducted without hazards to bald eagles. Investigations also are needed to determine whether dioxins are bioaccumulating in bald eagles and other organisms at hazardous concentrations. More controls on the use and disposition of substances containing PCB's are needed, and all transformers and circuit breakers on hydroelectric dams and major waterways should be checked and replaced if they contain PCB's.

LITERATURE CITED

ABBOTT, J. M. 1967. The Chesapeake bald eagles. Atl. Nat. 22:20–25.

ANDERSON, D. W., AND J. J. HICKEY. 1972. Eggshell changes in certain North American birds. Proc. Int. Ornithol. Congr. 15:514–540.

BITMAN, J., H. C. CECIL, S. J. HARRIS, AND G. F. FRIES. 1969. DDT induces a decrease in eggshell calcium. Nature 224:44–46.

BROLEY, C. L. 1958. The plight of the American bald eagle. Audubon 60:162–171.

CECIL, H. C., J. BITMAN, R. J. LILLIE, G. F. FRIES, AND J. VERRETT. 1974. Embryotoxic and teratogenic effects in unhatched fertile eggs from hens fed polychlorinated biphenyls (PCBs). Bull. Environ. Contam. Toxicol. 11:489–495.

CHARNETSKI, W. A. 1976. Organochlorine insecticide residues in ducklings and their dilution by growth. Bull. Environ. Contam. Toxicol. 16:138–144.

CROMARTIE, E., W. L. REICHEL, L. N. LOCKE, A. A. BELISLE, T. E. KAISER, T. G. LAMONT, B. M. MULHERN, R. M. PROUTY, AND D. M. SWINEFORD. 1975. Residues of organochlorine pesticides and polychlorinated biphenyls and autopsy data for bald eagles, 1971–72. Pestic. Monit. J. 9:11–14.

EISLER, R. 1986. Dioxin hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildl. Serv. Biol. Rep. 85/1.8. 37pp.

FRENZEL, R. W. 1984. Environmental contaminants and ecology of bald eagles in southcentral Oregon. Ph.D. Thesis, Oregon State Univ., Corvallis. 143pp.

GRIER, J. W. 1974. Reproduction, organochlorines, and mercury in northwestern Ontario bald eagles. Can. Field-Nat. 88:469–475.

———. 1982. Ban of DDT and subsequent recovery of reproduction in bald eagles. Science 218: 1232–1235.

GRUBB, T. G., S. N. WIEMEYER, AND L. F. KIFF. 1990. Eggshell thinning and contaminant levels in bald eagle eggs from Arizona, 1977 to 1985. Southwest. Nat. 35:298–301.

HAMERSTROM, F., T. RAY, C. M. WHITE, AND C. E. BRAUN. 1975. Conservation committee report on the status of eagles. Wilson Bull. 87:140–143.

HARRIS, M. P., AND D. OSBORN. 1981. Effects of a polychlorinated biphenyl on the survival and breeding of puffins. J. Appl. Ecol. 18:471–479.

HASELTINE, S. D., AND R. M. PROUTY. 1980. Aroclor 1242 and reproductive success of adult mallards (*Anas platyrhynchos*). Environ. Res. 23:29–34.

———, G. H. HEINZ, W. L. REICHEL, AND J. F. MOORE. 1981. Organochlorine and metal residues in eggs of waterfowl nesting on islands in Lake Michigan off Door County, Wisconsin, 1977–78. Pestic. Monit. J. 15:90–97.

HATCH, W. R., AND W. L. OTT. 1968. Determination of sub-microgram quantities of mercury by atomic absorption spectrophotometry. Anal. Chem. 40:2085–2087.

HEINZ, G. H. 1979. Methylmercury: reproductive and behavioral effects on three generations of mallard ducks. J. Wildl. Manage. 43:394–401.

HENNY, C. J. 1972. An analysis of the population dynamics of selected avian species with special reference to changes during the modern pesticide era. U.S. Fish Wildl. Serv., Wildl. Res. Rep. 1. IV + 99 pp.

———, L. J. BLUS, S. V. GREGORY, AND C. J. STAFFORD. 1981. PCBs and organochlorine pesticides in wild mink and river otters from Oregon. Pages 1763–1780 *in* J. A. Chapman and D. Pur-

sley, eds. Worldwide Furbearer Conf. Proc., Frostburg, Md.

———, ———, A. J. KRYNITSKY, AND C. M. BUNCK. 1984. Current impact of DDE on black-crowned night-herons in the intermountain west. J. Wildl. Manage. 48:1–13.

HICKEY, J. J., AND D. W. ANDERSON. 1968. Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds. Science 162:271–273.

HINDERBERGER, E. J., M. L. KAISER, AND S. R. KOIRTYOHANN. 1981. Furnace atomic absorption analysis of biological samples using the L'vov platform and matrix modification. At. Spectroscopy 2:1–7.

ISAACS, F. B., R. G. ANTHONY, AND R. J. ANDERSON. 1983. Distribution and productivity of nesting bald eagles in Oregon, 1978–1982. Murrelet 64: 33–38.

KAISER, T. E., W. L. REICHEL, L. N. LOCKE, E. CROMARTIE, A. J. KRYNITSKY, T. G. LAMONT, B. M. MULHERN, R. M. PROUTY, C. J. STAFFORD, AND D. M. SWINEFORD. 1980. Organochlorine pesticide, PCB, and PBB residues and necropsy data for bald eagles from 29 states, 1975–1977. Pestic. Monit. J. 13:145–149.

KOZIE, K. D. AND R. K. ANDERSON. 1991. Productivity, diet, and environmental contaminants in bald eagles nesting near the Wisconsin shoreline of Lake Superior. Arch. Environ. Contam. Toxicol. 20:41–48.

KRANTZ, W. C., B. M. MULHERN, G. E. BAGLEY, A. SPRUNT, IV, F. J. LIGAS, AND W. B. ROBERTSON, JR. 1970. Organochlorine and heavy metal residues in bald eagle eggs. Pestic. Monit. J. 3:136–140.

KUBIAK, T. J., H. J. HARRIS, L. M. SMITH, T. R. SCHWARTZ, D. L. STALLING, J. A. TRICK, L. SILEO, D. E. DOCHERTY, AND T. C. ERDMAN. 1989. Microcontaminants and reproductive impairment of the Forster's tern on Green Bay, Lake Michigan—1983. Arch Environ. Contam. Toxicol. 18:706–727.

KUEL, D. W., B. C. BUTTERWORTH, A. MCBRIDE, S. KRONER, D. BAHNICK. 1989. Contamination of fish by 2,3,7,8-tetrachlorodibenzo-p-dioxin: a survey of fish from major watersheds in the United States. Chemosphere 18:1997–2014.

LINCER, J. L. 1975. DDE-induced eggshell thinning in the American kestrel: a comparison of the field situation and laboratory results. J. Appl. Ecol. 12: 781–792.

LONGCORE, J. R., AND F. B. SAMSON. 1973. Eggshell breakage by incubating black ducks fed DDE. J. Wildl. Manage. 37:390–394.

MCALISTER, K. R., T. E. OWENS, L. LESCHNER, AND E. CUMMINS. 1986. Distribution and productivity of nesting bald eagles in Washington, 1981–85. Murrelet 67:45–50.

MCLANE, M. A. R., AND D. L. HUGHES. 1980. Reproductive success of screech owls fed Aroclor 1248. Arch. Environ. Contam. Toxicol. 9:661–665.

MONK, H. E. 1961. Recommended methods of analysis of pesticides residues in food stuffs. Rep. by the Joint Mercury Residues Panel. Analyst 86: 608–614.

NATIONAL ACADEMY OF SCIENCES, NATIONAL ACADEMY OF ENGINEERING. 1973. Water quality criteria 1972. Environ. Prot. Agency, Washington, D.C., Ecol. Res. Ser., EPA-R3-73-033. 594pp.

NEWTON, I. 1979. Population ecology of raptors. Buteo Books, Vermillion, S.D. 399pp.

PORTER, R.D., AND S. N. WIEMEYER. 1969. Dieldrin and DDT: effects on sparrow hawk eggshells and reproduction. Science 16:199–200.

POSTUPALSKY, S. 1974. Raptor reproductive success: some problems with methods, criteria, and terminology. Pages 21–31 *in* F. N. Hamerstrom, Jr., B. E. Harrell, and R. R. Ohlendorff, eds. Management of raptors. Proc. Conf. Raptor Conserv. Tech., Raptor Res. Report No. 2.

SCHMITT, C. J., J. L. ZAJICEK, AND M. A. RIBICK. 1985. National pesticide monitoring program: residues of organochlorine chemicals in freshwater fish, 1980–81. Arch. Environ. Contam. Toxicol. 14:225–260.

SEELYE, J. G., R. J. HESSELBERG, AND M. J. MAC. 1982. Accumulation by fish of contaminants released from dredged sediments. Environ. Sci. Technol. 16:459–464.

SERVHEEN, C. W. 1975. Ecology of the wintering bald eagles on the Skagit River, Washington. M.S. Thesis, Univ. Washington, Seattle. 96pp.

SMITH, L. M., D. L. STALLING, AND J. L. JOHNSON. 1984. Determination of part-per-trillion levels of polychlorinated dibenzofurans and dioxins in environmental samples. Anal. Chem. 56:1830–1842.

SOUTHERN, W. E. 1964. Additional observations on winter bald eagle populations: including remarks on biotelemetry techniques and immature plumages. Wilson Bull. 76:121–137.

SPRUNT, A., IV, AND F. J. LIGAS. 1966. Audubon bald eagle studies—1960–1966. Proc. Annu. Nat. Audubon Soc. Meet. 62:25–30.

STEIDL, R. J., C. R. GRIFFIN, AND L. J. NILES. 1991. Contaminant levels of osprey eggs and prey reflect regional differences in reproductive success. J. Wildl. Manage. 55:601–608.

STICKEL, L. F. 1973. Pesticide residues in birds and mammals. Pages 254–312 *in* C. A. Edwards (ed.). Environmental pollution by pesticides. Plenum Press, New York, N.Y.

———. N. J. CHURA, P. A. STEWART, C. M. MENZIE, R. M. PROUTY, AND W. L. REICHEL. 1966. Bald eagle pesticide relations. Trans. North Am. Wildl. Nat. Res. Conf. 31:190–200.

U.S. ENVIRONMENTAL PROTECTION AGENCY. 1986. Quality Criteria for water 1986. Environ. Prot. Agency, Washington, D.C., EPA 440/5-86-001.

U.S. FISH AND WILDLIFE SERVICE. 1979. List of endangered and threatened wildlife and plants. Fed. Register 44:3644.

———. 1986. Recovery plan for the Pacific bald eagle. U.S. Fish and Wildl. Serv., Portland, Oreg. 160pp.

WATSON, J. W., M. G. GARRETT, AND R. G. ANTHONY. 1991. Foraging ecology of bald eagles in the

Columbia River estuary. J. Wildl. Manage. 55: 492–499.

WIEMEYER, S. N., AND R. D. PORTER. 1970. DDE thins eggshells of captive American kestrels. Nature 227:737–738.

———, T. G. LAMONT, C. M. BUNCK, C. R. SINDELAR, F. J. GRAMLICH, J. D. FRASER, AND M. A. BYRD. 1984. Organochlorine pesticide, polychlorobiphenyl, and mercury residues in bald eagle eggs—1969–79—and their relationships to shell thinning and reproduction. Arch. Environ. Contam. Toxicol. 13:529–549.

———, B. M. MULHERN, F. J. LIGAS, R. J. HENSEL, J. E. MATHISEN, F. C. ROBARDS, AND S. POSTUPALSKY. 1972. Residues of organochlorine pesticides, polychlorinated biphenyls, and mercury in bald eagle eggs and changes in shell thickness—1969 and 1970. Pestic. Monit. J. 6:50–55.

Received 4 December 1990.
Accepted 13 August 1992.
Associate Editor: Morrison.